ON THE CAUSES OF THE DEFORMATION OF THE EARTH'S CRUST.

Mountain-making.

By eminent geologists it has been shown that the contraction hypothesis is not sufficient to account for the observed deformations of the earth's crust. We are obliged to look for other causes of deformation.

The form of a cosmic body must be irregular if the masses are unequally mixed. Already in the liquid stage under this condition a geoid is formed. The radius with dense material must be shorter, so much as to equilibrate the higher regions with less density.

This cause of constant irregularity is not sufficient to explain the existing differences of level. In fact, depressions and elevations are not the result of a constant equilibrium; they are not permanent. Sedimentation and erosion disturb the mechanical and the thermal equilibrium and cause a continual deformation of our planet. Another cause of deformation is found in the continual shifting of material. Accumulation of eruptive material and of sediments (loading) on one side, and erosion (disburdening) on the other side, cause deformations of the earth's crust. If the plasticity of the cosmic body is great, the surface of the burdened and disburdened regions has the tendency to remain nearly level—a quasi-hydrostatic (a "magmastatic") equilibrium will dominate.

As the material of our earth is not very plastic, and as other causes of deformation have a contrary effect, it is natural that geological facts are not in accordance with this hypothesis.

Contradictory to this hypothesis are the facts (1) that subsidence does not continue as long as sedimentation goes on; (2) that sinking often is considerable, though the loading is slight; (3) that in many cases enormous loading does not produce a depression of the earth's crust (volcanic chains growing up on a highland).

The Thermal Theory.

The constant disturbance of thermal equilibrium is of the highest importance. Sedimentation causes an ascending movement of the geo-isotherms: expansion and general elevation. If the dilatation is concentrated, there may result a fold-chain (Hall, Reade). The hypothesis is supported by the fact that the elevation and folding always drives up sediments, which were formed immediately before the orogonic movement. The mountains grow up from a shallow sea, they are never generated in the middle of a continent, which might as well occur according to the contraction-hypothesis.

Messrs. Fisher, Hutton, and Reade have considered the thermal effect, and agree that it is sufficient to produce considerable deformations. But to produce a mountain-chain of some 1000 m., we must suppose a concentration of the effect in one zone, as long as we, according to Mr. Reade, consider only the effect of thermal expansion in the earth's crust.

As physical geology considers the earth as a rigid body (the plasticity, according to Mr. G. Darwin, being that of steel) there is no reason why the thermal expansion ought not to proceed through the rigid magma to the region of constant temperature. The increase of temperature being 3° C. for 100 m., the temperature at the depth of 40 km. = 1200° C., at 50 km. = 1500° C. After sedimentation of 10 km. the base of the sediments is warmer by 300°. The underlying masses are equally warmer by this quantity.

The linear expansion of rocks per 100° C. is nearly = 1 per mille, *i.e.* 1 metre per km. In our case the expansion is = 3 m. per km. Lateral expansion being impossible, it results in a vertical elevation of nearly 1 per cent. The *crust* would be elevated through the full expansion by 500 metres.

If we consider the thermal expansion proceeding to a depth of 500 or 1000 km. through the rigid magma, we find that indeed highlands and chains of some 1000 m. may be driven up, even if we do not suppose a concentration of the thermal effect on a restricted zone.

Yet certain facts are not in accordance with the theory thus formulated. (1) Elevation and mountain-making is not a slow and constant process, but it is executed in a short time (relatively). (2) Folding in some cases does not reach to a considerable depth, but we often meet undisturbed masses below the folded complex. These facts induce us to modify the hypothesis.

Messrs. Gilbert and Suess have shown that the movement of folding is horizontal and superficial; we may consequently ask whether folding may not be caused by a *gliding* movement (see my "Theoretical Geology").

If we deposit under water sediments of great plasticity, and if we incline afterwards the masses to the extent of 5° or 10°, there succeeds a gliding movement, especially if the sediments partly emerge from the water-level, and if occasional shaking (earthquakes) occurs.

The gliding masses form a fold-chain. The Silurian of Christiania is intensely folded, but it rests on an undisturbed base (Brögger). The folded Jurassic strata of the Weser chain likewise repose on an unfolded base. In such cases it is impossible to derive folding from a general contraction, nor can we explain the quiet base by supposing a concentration of thermal expansion in certain districts. The existence of a quiet base is explained only if we admit folding to be in such cases a gliding process.

The fact that folding in nature is accompanied by emersion is in accordance with these views.

Contradictory to this hypothesis seems the fact that the hypothetical land (from which the folded sediments were pushed towards the lowland) in the back of the chain is often wanting, and that in its place a (marine or a terrestrial) depression exists. This objection disappears if we pursue the process, and we find that this seemingly contradictory fact indeed must result: partial cooling causes local depression. Erosion has the same effect. If 1 km. (vertical measure) of rock mass is denuded, the temperature of the new surface is lower by 30° C. than it was at this point before erosion occurred. This cooling propagates into depth, and the denuded land gets depressed.

The highland, from which the sediments glide away, must sink down in course of time. The Jura is pushed towards the French plain; in the back is situated the depression of Neuchatel. Here, according to the deduction, existed a highland, which subsided in consequence of cooling. Between the fold-chain and the depressed district are situated deep ruptures, along which earthquakes occur as long as the depression goes on.

East of the Appalachian Mountains, as late as the end of the Palæozoic era, a highland was situated, wherefrom the detritus-masses were transported into the Appalachian sea. Afterwards the Carboniferous emersion occurred (in consequence of thermal expansion) and the Palæozoic sediments were pushed towards the western lowland; here the Appalachian chain was generated. Erosion and consequent cooling, instead of the old elevation, caused a depression in the eastern region, which got inundated by the ocean.

In course of time the adjoining districts have changed parts. In the lowland a chain is driven up and the old highland sinks down.

Eruptive districts form depressions with growing accumulations. The thermal effect in course of time leads to an opposite movement. Material of 1000° C. flows through many fissures and covers the surface. The eruptive region, in consequence, gets heated in a higher degree than by simple sedimentation. The period of depression in this case, too, in course of time, gives way to a contrary movement.

It is obvious that elevation and subsidence, in volcanic as well as in sedimentary districts, must alternate, as we indeed observe. Compression, metamorphism, and loading cause a negative movement in the sedimentary districts (geosyncline); warming causes elevation; erosion again creates subsidence. These positive and negative factors at different times have different values, and partly compensate each other. Therefore elevation and subsidence are often observed to alternate.

The greatest contrasts must occur where a highland joins the sea; here sedimentation and erosion cause a considerable shifting of material; loading and unloading, as well as great thermal contrasts, dominate in these regions.

The positive and negative movements of the sea-level are not important; but the amplitude of deformation at the boundary between high land and sea is in some cases as great as 20,000 metres.

The hydrosphere is relatively constant, whereas the crust executes oscillations of long duration and great amplitude.

If we want to study in an experiment the formation and motion of a lava-stream, it cannot be our wish to observe the motions of an enormous quantity of a body as viscid and as hot as lava through long time; that would be mere observation, and not experiment. In a real experiment we observe the motion of a small quantity of a less rigid material for some hours or days.

If we observe in nature folded strata of hard sandstone and of soft shale or clay, we shall be satisfied to imitate the deformation of the latter masses; and instead of the hard sandstone, we will take substances as unplastic, but so brittle that they yield to the small forces employed in our experiment.

So we may produce on a small scale, with application of little force and in a short time, the same effect which we observe in nature on a large scale.

If we succeed in producing experimentally the same phases of deformation, the same mechanical effect as in nature, if we see fold-chains and complicated eruptive massives growing up with their characteristic features, we shall be obliged to attribute to these experiments a high importance for mechanical geology.

In my experiments I evaporated muddy material (clay, mud) or plaster of Paris, which consolidates slowly in consequence of an admixture of glue. The strata were differently coloured: some thin strata, consisting of plaster-powder, were brittle, and underwent ruptural deformation, whereas the other masses showed plastic deformation. The whole system reposed on a base, which, according to the plasticity of the material, was inclined by 5° to 15°.

As soon as the inclination attained a certain limit, the whole complex begins to glide towards the lowland. The sediments get folded to a considerable depth; faults occurred between districts of diverse motion. The gliding deformation occurred rapidly whenever the base was shaken slightly (earthquakes). The experiment being finished, we let the masses consolidate; afterwards we may prepare profile-cuts, which may be executed with the saw, if we evaporated plaster.

The cuts are instructive, if the strata are differently coloured.

If we mark certain points in the originally level strata, or if we divide the whole system into cubes, we may study the locomotion and deformation of every point, line, square, or cube of our system; the vertical, as well as the horizontal component of displacement, may be observed and measured.

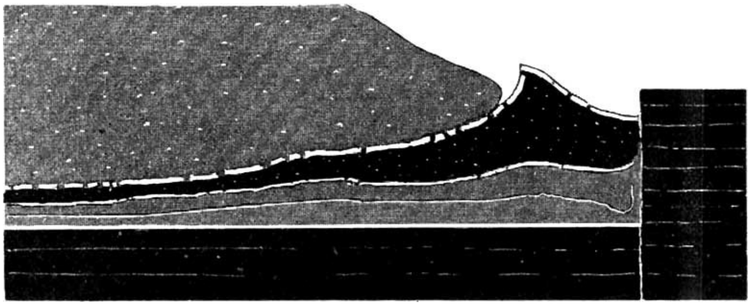

FIG. 1.

The following experiments explain some points in this theoretical essay:—

The plastic sediments are loaded by a mass, and get deformed in the manner illustrated by Fig. 1. The black base and the black side-wall at the right hand (fault scarp) are rigid; the plastic strata are pushed up in form of a fold; the highest white stratum is rigid, and gets torn into clods.

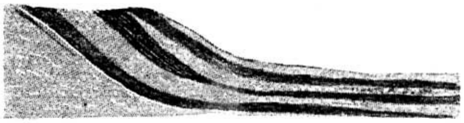

FIG. 2.

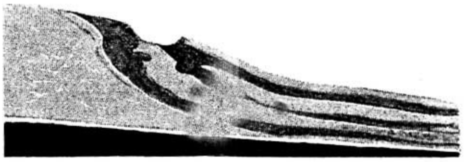

FIG. 3.

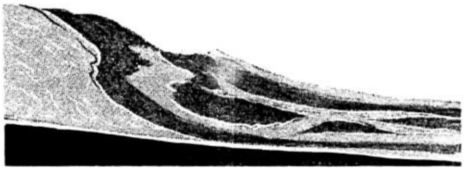

FIG. 4.

Figs. 2-4 show successive stages. A delta, deposited under water, gets elevated, it emerges; the masses are shaken slightly and glide over the inclined base. Folding succeeds, as Figs. 3 and 4 show.

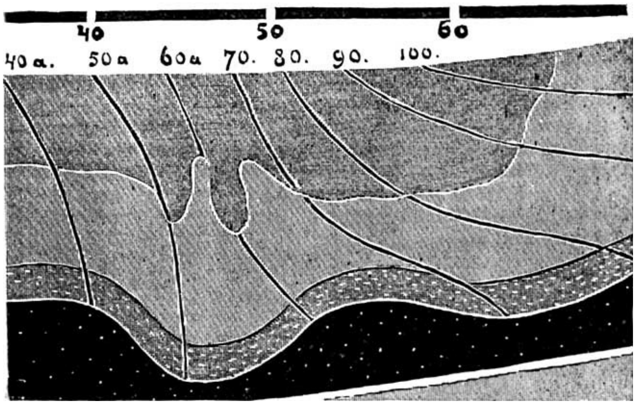

FIG. 5.

In Fig. 5 the strata, gliding over the inclined plane to the left, were divided by vertical lines. Distance of lines = 0·1 metre. At the top of the figure the fixed scale is noted. Point 40*a* of the strata originally lay directly below the scale-point 40, 60*a* was placed below 60, and so on.

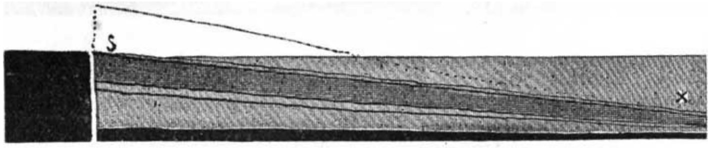

FIG. 6.

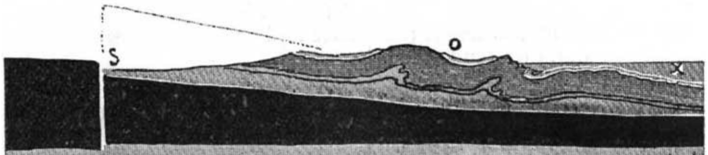

FIG. 7.

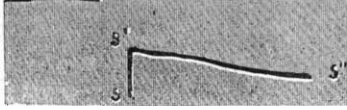

FIG. 8.

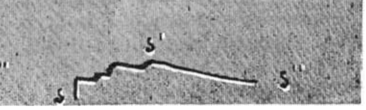

FIG. 9.

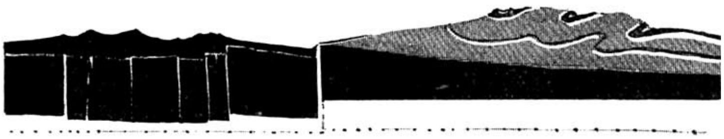

FIG. 10.

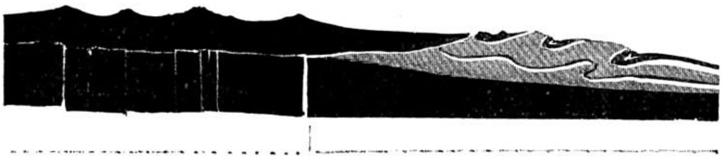

FIG. 11.

We see at once the amount of horizontal (gliding) movement. The vertical lines are deformed in the direction of the motion. The parts near the base move little, the parts near the surface have a higher velocity, so that the vertical lines of division get curved. The motion being intense in the highland (at the right hand), the vertical lines in this region are pushed over and assume a flat position.

The surface of the gliding masses in this case remained level, as the material was very plastic; yet folding in the depth of the masses is remarkable. We see that a fold chain may have a wide surface; the intensely folded regions get exposed only after an extensive erosion or abrasion occurred. This experiment shows also how the motion and the amount of folding decrease in the direction towards the base.

Figs. 6 and 7 illustrate my conception of the process of glide-folding as it occurs in nature. The black parts form the solid basement; at S we observe a fault scarp (the coast of a continent). In the sea the sediments SX are deposited. Warming of the newly-deposited masses, and of the lower parts of the earth's crust, in course of time elevates the sediments, as the dotted line in Fig. 6 notes. The sediments glide over the inclined plane towards the right, and form a fold-chain, O.

The motion of a single point is noted in Fig. 8. Point S first gets elevated (through thermal intumescence) to S′, and then it glides towards S″. In most cases the way described by a point is complicated, as Fig. 9 illustrates. Elevation having reached a certain degree, the masses glide a little, elevation continues, again gliding succeeds, and so on.

The highland in the back of the fold-chain (black mass at the left hand) gets eroded; cooling causes a subsidence of this region, the earth's crust breaks, and through the fissures and faults, in many cases, eruptive material escapes. A volcanic chain is built up in the back of the fold-chain (Fig. 10). In course of time the fold-chain may be covered partly by the volcanic chain (Fig. 11). Fig. 12 (profile), and Fig. 13 (surface of the same experiment) show that pulling (tearing) and pushing (folding) are *reciprocal processes.* The strata, gliding away from the highland, are torn in this district, whereas compression and folding occur in the lowland.

The surface of the strata (Fig. 13) was divided into squares of different colour (like a chess-board), so that we may see and measure directly the direction and amount of pushing and pulling in both districts. Black fissures occur at the left hand, grey folds at the right hand.

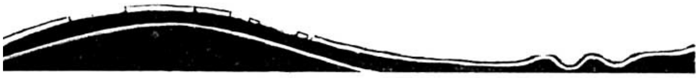

FIG. 12.

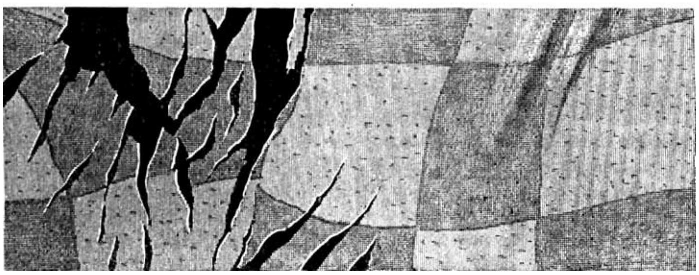

FIG. 13.

The base in this, as in the other cases, was rigid; there occurred *no compression in the depth*, yet folding succeeded in the gliding strata.

Folding, according to my opinion, does not depend on a contraction of our planet, but is a simple gliding phenomenon.

E. REYER.

NOTES.

AT the meeting of Section A of the British Association on Monday, August 8, there will be a discussion on the subject of a National Physical Laboratory. The discussion will be opened by Prof. Oliver J. Lodge, F.R.S.

THE Academy of Sciences at Berlin has conferred upon Lord Kelvin one of the first four Helmholtz gold medals.

THE French Association for the Advancement of Science will hold its twenty-first meeting at Pau from September 15 to 22.

THE Council of University College have accepted a tender for the erection of new technical laboratories for the practical teaching of mechanical and electrical engineering. Care has been taken that the buildings shall accord with all the conditions of modern teaching, but of course it is necessary that provision shall also be made for an adequate supply of apparatus and plant. The part of the proposed laboratory which is to be set apart for electrical engineering cannot be properly fitted up for a sum of less than £2010, and Prof. Fleming has issued an appeal to all who may be able and willing to help him in obtaining this amount. In the course of his appeal he says: "The Council do not at present see their way to incur this additional expenditure over and above the cost of the buildings, and yet it is absolutely essential to the completion of the project. The Council have, therefore, by a minute of their proceedings of May 7, 1892, recommended this very essential part of the proposed work to the notice and liberality of those who may be disposed to help. Thus sanctioned and authorized by the Council, the Professor of Electrical Engineering begs permission to bring under your notice the necessity for a special Electrical Apparatus Fund, and desires to invite your aid in the formation of such a fund of £2010, to be entitled 'The University College Electrical Engineering Apparatus Fund.'" Prof. Fleming is anxious that the sum should, if possible, be obtained within the next six months. Donations should be sent to the Secretary of University College, marked "Electrical Apparatus Fund."

THE services rendered by the late Sir William Macleay to the Linnean Society of New South Wales and to science in general are to be commemorated by the publication of a memorial volume. This was decided recently at a general meeting of the New South Wales Linnean Society. It is proposed that, in addition to a portrait and memoir of Sir William Macleay, the volume shall consist of original papers on those branches of science in the advancement of which he was especially interested—zoology, ethnology, botany, and geology. Promises of papers have already been received from Sir F. von Mueller, Prof. Hutton, Prof. J. Parker, Prof. Baldwin Spencer, and other leading Australian biologists. It is intended that, as regards "style of get up and illustration," the volume shall be fully worthy of the occasion. The expense is to be met by means of a public subscription. Every ordinary member of the Society subscribing one guinea or upwards, and any non-member subscribing two guineas or upwards, to the memorial will receive a copy of the volume. At the meeting of the Society on May 25, the President announced that a number of subscriptions had been received in answer to a circular issued a few weeks previously. It was necessary, however, he said, that a considerably larger sum should be collected before the Council would be in a position to proceed with the work.

THE Governors of the Merchant Venturers' School, Bristol, have elected to the vacant Lectureship in Biology Mr. G. P. Darnell-Smith, B.Sc., assistant to Dr. W. Marcet at University College, London. Mr. Smith is a student of University College, and graduated with honours in botany and zoology in 1891.

THE thunderstorms which we referred to in our last issue gave a very decided, but temporary, check to the temperature, the highest day readings falling about 20° after the storm; and the heavy rains which accompanied the disturbed weather have materially lessened the deficiency of rainfall, which has been so characteristic a feature for some months past. By the end of last week the temperature had recovered, and the weather became very fine in the southern parts of the kingdom, the maxima reaching from 80° to 85° at some inland stations on Sunday; while conditions remained unsettled, with heavy rain, in the north and west, owing to a cyclonic area which passed along the Irish coast, and caused a thunderstorm on the east coast. During the last day or two, depressions have passed to the northward of our islands, again causing unsettled weather, with rain in most parts; while the westerly winds have increased considerably in strength, reaching the force of a gale on our north-west coasts.